TECHNICAL REFERENCE DOCUMENT

PROTECT AND MONITOR WATER RESOURCES

1. Introduction

The availability and quality of freshwater supplies for human and ecological needs are critical factors influencing the health and livelihoods of all people in the nation. Growth in human population and water use, degradation of water supplies by contamination, and recognition of the legitimate needs for freshwater in order to support critical ecosystem functions may lead to increasing scarcity and conflict over freshwater supplies in coming years. Water conflicts, which once were confined largely to the arid parts of the country, are now becoming increasingly common in the humid parts, as well. The potential for alterations in climate creates an even stronger need for reliable information about the status of freshwater resources. While this report is entitled "Protect and Monitor Water Resources", this title actually reflects intermediate goals. The end goals toward which the efforts described in this chapter are directed are more clearly stated as "ensuring water availability and quality for both human and ecological needs, and minimizing conflicts over water resources."

2. User Requirements

Informed resource management begins with accurate information on both supply and use of freshwater. The first step is basic measurements of the fluxes and storage of water in a watershed and its underlying aquifer system (Figure 1).

Precipitation, streamflow, lake and reservoir storage, evaporation and transpiration, soil moisture, ground-water storage, ground-water recharge and discharge; and withdrawals for various uses should all be measured. Concentrations and loads of various significant natural and anthropogenic contaminants must also be measured to determine their impact on water availability and on aquatic habitats in freshwater, estuarine, and marine environments. Most of these measurements must be made using *in situ* sensors, sampling, and manual measurement techniques, but some can be done using remote sensing. Temporal variability and long-term trends in these measures of availability must be recorded and documented. This long-term, dense hydrologic database is needed in order for scientists, water managers and policy makers to make appropriate decisions regarding prediction of future conditions including floods and droughts, ground-water depletion, and reservoir storage. The data are also needed in order to develop accurate assessments and simulation tools to support decision-making related to the effects of alternative future water-use scenarios on water supplies, and the effects of various land- and chemical-use scenarios on the quality and quantity of freshwater resources.

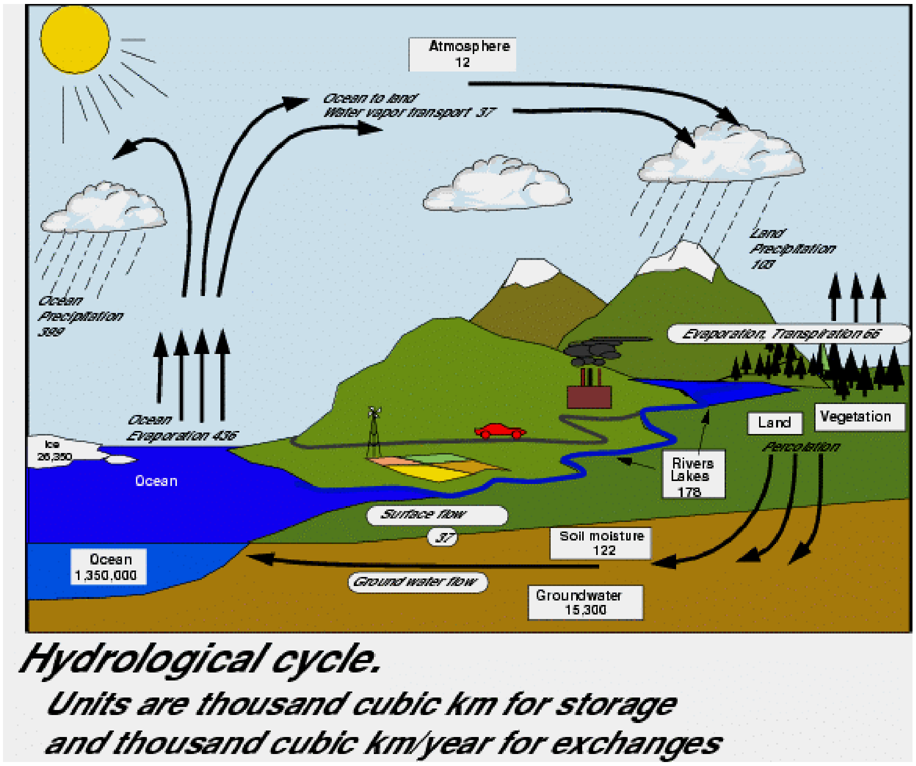


Figure 1: The hydrologic cycle and estimates of storage and fluxes

3. Existing Capabilities and Commonalities

Observations for monitoring and protecting water resources are made by several Federal agencies. The observations include monitoring of fluxes and storage in the various components of the hydrologic cycle, and monitoring of chemical and biological characteristics of water resources. Monitoring systems include networks of manually operated observation stations and sampling sites, networks of *in situ* sensors, remote sensing systems, and modeling based on various combinations of all three. There are some examples of strong coordination and collaboration among agencies, but it is currently not possible to go to one single source for comprehensive water-resources monitoring information. Notable examples of water-resources monitoring programs are described below:

Precipitation

Precipitation quantity monitoring is done by NOAA using a combination of ground-based observation stations and remote sensing. The ground-based daily observation network comprises about 5,000 stations associated with the 13 River Forecast Centers and several hundred stations associated with the Climate Anomaly Database (http://www.cpc.ncep.noaa.gov/). These stations provide national coverage at a resolution of about ¼ degree of latitude and longitude (http://www.cpc.noaa.gov/cgi-bin/station_realtime.sh).

A typical product from the precipitation monitoring network is the 24-hour precipitation quantity map: (http://www.cpc.noaa.gov/products/precip/realtime/us_precip.html).

NOAA also makes available on its web site high-resolution radar data from the national network of Next Generation Radar (NEXRAD) is now available in real time to government, university and private sector users. NEXRAD data are used in quality control of the ground-based monitoring data (http://www.roc.noaa.gov/reflect.asp).

For global precipitation monitoring, NOAA's Global Precipitation Climatology Project in the Climate Prediction Center collects precipitation quantity data from ground-based networks worldwide, and also uses remote sensing to estimate precipitation for the globe.

Snow

Snowfall is of particular interest to water-resources managers because of the seasonal storage of water in the snowpack. NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) provides remotely-sensed and modeled hydrology products for the conterminous U.S. and Alaska. The NOHRSC national and regional snow analyses provide a daily synoptic overview of snow conditions for the conterminous U.S. as well as for the 18 U.S. snow regions at a higher resolution. The snow analyses are text descriptions of daily snow accumulation based on snow observations and modeled snowpack characteristics. They review both the meteorological observations of snowfall and snow on the ground as well as the snowfall and snow accumulation simulated by the NOHRSC snow model. Unique snow data observations such as airborne snow water equivalent estimates are reviewed in the text product during the course of operational airborne snow survey missions. Image maps of snow characteristics and other graphics summaries are hyper-linked in the analyses to highlight specific points of interest. The snow analyses are prepared each weekday by NOHRSC personnel. Snowfall maps are available for the most recent 1, 2, 3 and 7-day period by state or for the entire nation. Also available are current snow depth maps (http://lwf.ncdc.noaa.gov/oa/climate/research/snow/recent.html), snow water equivalent maps (http://www.nohrsc.nws.gov/nsa/), and snowmelt maps (http://www.nohrsc.nws.gov/nsa/). NOAA also disseminates national maps of recent snowfall and snow depth: (http://lwf.ncdc.noaa.gov/oa/climate/research/snow/recent.html).

The Natural Resources Conservation Service (NRCS) National Water and Climate Center installs, operates, and maintains an extensive, automated system to collect snowpack and related climatic data in the Western United States called SNOTEL (for SNOwpack TELemetry) (http://www.wcc.nrcs.usda.gov/about/nwcc-function.html); photo of snowtel station (http://www.wcc.nrcs.usda.gov/snow/). The system evolved from NRCS's Congressional mandate in the mid-1930's "to measure snowpack in the mountains of the West and forecast the water supply." The programs began with manual measurements of snow courses; since 1980, SNOTEL has used telemetered data from 600 automated sensors in 11 western states including Alaska.

SNOTEL uses meteor burst communications technology to collect and communicate data in near-real-time. VHF radio signals are reflected at a steep angle off the ever present band of ionized meteorites existing from about 50 to 75 miles above the Earth. Satellites are not involved; NRCS operates and controls the entire system. The sites are generally located in remote high-mountain watersheds where access is often difficult or restricted. Access for maintenance by NRCS includes various modes from hiking and skiing to helicopters. For example, to see the distribution of SNOTEL sites in Wyoming, visit http://www.wcc.nrcs.usda.gov/snotel/Wyoming/wyoming.html. For an annual graph of snowpack data from USDA SNOTEL site in Wyoming showing departure from normal precipitation and snow water equivalent, visit http://www.wcc.nrcs.usda.gov. For a map of the mountain snowpack of the western U.S. as monitored by USDA NRCS SNOTEL network, visit ftp://ftp.wcc.nrcs.usda.gov/downloads/wsf/jan04wsfwww.pdf.

Precipitation Quality
The National Atmospheric Deposition Program coordinates an interagency network of 250 precipitation quality monitoring stations to monitor the acidity of precipitation as well as other constituents such as nitrates, sulfates, and ammonia (http://bqs.usgs.gov/acidrain/). Annually the data are disseminated in several forms, including national maps: (http://nadp.sws.uiuc.edu/isopleths/maps2002/phlab.gif).

Streamflow
The U.S. Geological Survey (USGS) operates a national network of about 7,000 telemetered streamgages (http://waterdata.usgs.gov/nwis/rt, http://water.usgs.gov/nsip/. The network is supported jointly with other federal, state, and local governments. The number of gages in the network has been declining slightly in recent years as federal and state budgets have become tighter. The data are collected by automated water-level sensors and converted to streamflow according to empirical stage-discharge relations developed for each site. The stage-discharge relations are developed based on manual discharge measurements made about 8 times per year at each station. Automated water-level data are telemetered, generally using the GOES satellites, and are disseminated on the internet (http://waterdata.usgs.gov/nwis/rt).

Surface Water Quality
There are numerous federal, regional, state, tribal, and local monitoring programs for ambient surface water quality conditions and compliance monitoring (http://www.epa.gov/ebtpages/watewaterqualitymonitoring.html). Most of these data are input to EPA's Storage and Retrieval (STORET) database (http://www.epa.gov/storet/). EPA summarizes state and federal water-quality data annually in a national report on stream water quality. This National Water Quality Inventory Report to Congress (305(b) report) (http://www.epa.gov/305b/) is the primary vehicle for informing Congress and the public about general water quality conditions in the United States. This document characterizes our water quality, identifies widespread water quality problems of national significance, and describes various programs implemented to restore and protect our waters. It characterizes the following water body types as "good", "threatened", or "impaired", based on sampling results submitted by the states' rivers, streams, creeks, lakes, ponds, reservoirs, bays, estuaries and wetlands, coastal waters, ocean and near coastal waters. (http://oaspub.epa.gov/waters/w305b_report.nation).

The USGS conducts a nationwide monitoring and assessment program called the National Water Quality Assessment that includes a network of 6,100 stream-quality monitoring sites. (http://water.usgs.gov/nawqa/). Samples are analyzed for a wide variety of nutrients, pesticides, volatile organic compounds, metals, and biological indicators, and are compared with land-use data. Customized national maps of NAWQA data are available at http://water.usgs.gov/nawqa/data. The USGS SPARROW water-quality model uses observed water-quality data and a variety of basin characteristics to estimate concentrations and loads of several constituents nationwide, including unmonitored streams. For example, to see a map of model-estimated yields of nitrate-nitrogen from U.S. river basins estimated by the USGS SPARROW model based on water-quality sampling and basin characteristics, please visit http://water.usgs.gov/nawqa/sparrow/. Units are kg/square km/yr.

Another large-scale USGS stream monitoring program is the National Stream Quality Accounting Network (NASQAN), which routinely monitors stations on the nation's largest rivers, the Mississippi (including the Missouri and Ohio), the Columbia, the Colorado, the Rio Grande, and the Yukon. The Benchmark network monitors 48 stations on smaller, relatively pristine streams nationwide, and the Toxic Substances Hydrology Program includes more experimental monitoring of selected sites nationwide for organic wastewater contaminants including pharmaceuticals and endocrine-disrupting compounds. All USGS water-quality and water quantity data are stored in the National Water Information System (http://water.usgs.gov/nwis).

Water-quality data from both the EPA STORET database and the USGS National Water Information System can be accessed through a convenient single portal called "Window to My Environment" (http://www.epa.gov/enviro/wme/).

An important water-quality parameter that is a controlling factor for many total maximum daily load allocations as well as for determining the useful lifespan of many dams and reservoirs is suspended sediment. The USGS and several cooperating agencies have developed a suspended sediment database that provides daily concentrations and loads of sediment at many locations around the nation, plus ancillary data (http://water.usgs.gov/osw/suspended_sediment/index.html).

Monitoring of lake and reservoir water quality was formerly coordinated and funded under the Clean Lakes Program (http://www.epa.gov/owow/lakes/cllkspgm.html) but no appropriations have been made since 1994. Some lake monitoring is encouraged under the implementation of section 319 of the Clean Water Act. Additional monitoring is done by reservoir management agencies such as TVA, the Corps of Engineers, and the Bureau of Reclamation; and by the USGS, academic institutions, and other entities.

Lake and Reservoir Storage

Some of these data are included in the USGS National Water Information System (water.usgs.gov/nwis) as water-level data. Storage data are collected for individual projects by reservoir management agencies, typically using automated SCADA systems, but are not collected and reported on a national basis.

Evaporation and Transpiration

NOAA collects and disseminates nationwide evaporation data based on observations at weather stations equipped with evaporation pans (http://www.cpc.noaa.gov/products/soilmst/e.html). Some excellent academic and government studies of evaporation and transpiration are underway in selected areas.

Soil Moisture
For nationwide assessment and prediction purposes, soil moisture is estimated by a one-layer hydrological model using observed precipitation and temperature (http://www.cpc.noaa.gov/products/soilmst). A series of maps showing most recent day, monthly and 12 months calculated soil moisture, anomalies and percentiles have been archived (http://www.cpc.ncep.noaa.gov/soilmst/w.html).

A more sophisticated soil moisture product is the four-layer soil moisture estimate calculated in the Land Data Assimilation System (LDAS), based upon the NOAH four-layer land surface model. The North American LDAS is produced in real time at NOAA's National Center for Environmental Prediction, in collaboration with NASA and university partners (http://ldas.gsfc.nasa.gov). LDAS will lead to more accurate reanalysis and forecast simulations by numerical weather prediction (NWP) models, which typically have large errors in stores of soil moisture and energy and in turn, degrade the accuracy of forecasts.

Some additional promising experiments are underway by NASA and USDA to monitor soil moisture using satellites (http://hydrolab.arsusda.gov/smex03/). The NASA Aqua and Japanese ADEOS-II Advanced Microwave Scanning Radiometer Programs are working toward developing and providing daily soil moisture products.

The USDA Natural Resources Conservation Service also monitors soil moisture as part of their Soil Moisture/Soil Temperature Pilot project (SM/STPP), and disseminates a limited set of soil moisture data for the U.S. via the Soil Climate Analysis Network (http://www.wcc.nrcs.usda.gov/scan/).

Ground Water Storage
The USGS maintains a network of wells to monitor the effects of droughts and other climate variability on ground-water levels. The network consists of a national network of about 150 wells. Some of these have real-time telemetry, some have continuous records obtained periodically during field visits, and some have periodic manual measurements (http://groundwaterwatch.usgs.gov).

There are many thousands of monitoring wells that are measured by a variety of federal, state, local, and tribal agencies, but there is little coordination of the monitoring programs. In 2002 there were about 42,000 long-term observation wells in the U.S. with 5 or more years of record (http://water.usgs.gov/pubs/circ/circ1223/). Some aquifers have extensive ground-water-level trend data, some have little. One example of a well-monitored major aquifer is the High Plains Aquifer, in which water levels in 7,000 wells are measured annually (http://water.usgs.gov/wid/FS_215-95/FS_215-95.html).

Another good example of ground-water level monitoring is the Pennsylvania ground water network, which provides on-line maps and graphs of ground-water levels for every county in the state: (http://pa.water.usgs.gov/monitor/gw/index.html).

Drought Monitoring
The National Drought Mitigation Center at the University of Nebraska (http://drought.unl.edu/dm/), in cooperation with NOAA, USDA, and other agencies, assembles drought-related data from many sources and provides them on a single web site. There are good efforts underway to extend this drought monitoring to cover all of North America. Several data products are provided, along with a combined drought monitor map for the U.S. (http://www.drought.unl.edu/dm/monitor.html). Additional combinations of indicator variables should be considered for drought monitoring, including, for example, rangeland condition. NOAA has developed a plan, endorsed by the Western Governors Association, for a National Integrated Drought Information System that would provide enhanced monitoring capabilities, greater integration of data related to droughts, and enhanced forecasting capabilities. The plan is available at http://www.westgov.org/wga/publicat/nidis.pdf.

Ground Water Quality
Monitoring of ground-water quality is spotty. Most states have programs for ambient ground-water quality monitoring, but they are not coordinated as a national network. The USGS National Water Quality Assessment (NAWQA), which includes ground water, has water-quality data from 7,000 wells in its data warehouse (water.usgs.gov/nawqa/data).

Ground-Water Recharge and Discharge
These important components of the hydrologic cycle are usually estimated rather than measured directly. Availability and reliability of estimates varies greatly among U.S. aquifers. One example of a recent study with good estimates of recharge and discharge is a USGS study of the Middle Rio Grande aquifer system in the vicinity of Albuquerque, NM (http://water.usgs.gov/pubs/circ/2002/circ1222/).

Water Use
States and Federal agencies cooperate, with varying levels of effort, on measuring and estimating water use in various categories, resulting in national reports every 5 years (http://www.usgs.gov/features/wateruse.html). The most recent national compilation is an on-line report entitled "Estimated Use of Water in the United States in 2000" (http://water.usgs.gov/pubs/circ/2004/circ1268/)

The water use data compilation is a useful tool, but it has limitations. Data are reported only every 5 years. Data are collected at the county level, but are aggregated at the state level in the national report. Some water-use categories, such as irrigation and domestic supply, must be estimated because no accurate monitoring is done. There is a need for better monitoring of consumptive water use, which includes uses that do not return water to the surface or ground-water flow systems.

Drinking Water
The U.S. Environmental Protection Agency maintains several databases with nationwide information about drinking-water systems. The Safe Drinking Water Information System (SDWIS/FED) (http://www.epa.gov/safewater/sdwisfed/about_fed.html) contains data about locations and characteristics of the Nation's public drinking water systems, and about violations of

drinking-water standards or protocols. SDWIS/FED stores the information EPA needs to monitor approximately 175,000 public water systems.

States supervise the drinking water systems within their jurisdictions to ensure that each public water system meets state and EPA standards for safe drinking water. The Safe Drinking Water Act (SDWA) requires states to report drinking water information periodically to EPA; this information is maintained in SDWIS/FED. States report the following information to EPA:

- Basic information on each water system, including: name, ID number, number of people served, type of system (year-round or seasonal), and source of water (ground water or surface water)
- Violation information for each water system: whether it has followed established monitoring and reporting schedules, complied with mandated treatment techniques, or violated any Maximum Contaminant Levels (MCLs)
- Enforcement information: what actions states have taken to ensure that drinking water systems return to compliance if they are in violation of a drinking water regulation
- Sampling results for unregulated contaminants and for regulated contaminants when the monitoring results exceed the MCL

Currently, EPA is in the process of determining additional information states may be required to report in the future, such as the city and county where the system is located (most states already report this information), and the latitude/longitude of the source water intake.
EPA and USGS have collaborated on recent improvements in the locational data in SDWIS/FED, such that now accurate locations are available for all surface-water intakes and ground-water wells used for public supply. Due to the sensitive nature of the data, this database is not made available publicly.

For data on concentrations of contaminants in drinking water, EPA maintains a National Contaminant Occurrence Database (NCOD) (http://www.epa.gov/safewater/data/ncod.html). NCOD provides a library of water sample analytical data (or "samples data") that EPA is currently using and has used in the past for analysis, rulemaking, and rule evaluation. The drinking water sample data, collected at Public Water Systems, are for both regulated and unregulated contaminants. The data have been extensively checked for data quality and analyzed for national representativeness.

Within its National Water Quality Assessment Program, the USGS maintains a database of water quality data from domestic wells. Domestic wells are not regulated by EPA and do not contribute data to the EPA databases.

Land Use and Impervious Area

The way we use our land has a significant impact on our water resources. For that reason, spatial databases covering certain aspects of land use are of great importance in understanding, protecting, and predicting the quantity and quality of our water resources. The amounts and types of crops we grow, the extent of irrigated land, the types of best-management practices employed to protect watersheds, various practices related to forestry, mining, grazing, and urbanization all affect water resources. Of particular interest is the extent of impervious or paved area in any given watershed, since impervious area retards infiltration and contributes to quicker runoff and higher storm peak flows in streams. These land-use characteristics can be monitored with various remote sensing systems such as Landsat and Modis.

Wetlands

Wetlands are an important component of the hydrologic system, both biologically and hydrologically. They are monitored through the National Wetlands Inventory (http://wetlands.fws.gov), a program of the U.S. Fish and Wildlife Service. Wetland maps, developed through a combination of remotes sensing and ground-truth, are available in a number of formats.

National Hydrography Dataset

An important commonality of all of the surface-water related data mentioned above is the association of specific data with a specific stream reach in a network where flow relationships (upstream and downstream) are known. This spatial information is the core of the National Hydrography Dataset (NHD), a collaboration of EPA and USGS. NHD is a digital depiction of the stream reach network of the entire country, with each reach connected to the network in such a way that flow relationships are known. In many cases, point data mentioned above are associated with individual stream reaches in the NHD. In other cases, this association has yet to be made. The NHD is the key to linking surface water data with other geospatial coverages important to hydrology, such as digital elevation models (which help to describe drainage area boundaries and stream slopes), watershed boundaries, land cover and land use, and impervious area.

Synthesis of Hydrologic Information

Some synthesis of hydrologic datasets has been done at the National Weather Service Hydrologic Information Center (http://www.nws.noaa.gov/oh/hic/conds.shtml), the NWS Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/MD_index.html), the NOAA National Climatic Data Center (http://www.ncdc.noaa.gov/oa/climate/research/monitoring.html), and the National Drought Mitigation Center (http://www.drought.unl.edu/dm/current.html). A significant additional effort is underway as a collaboration among NOAA, the Drought Mitigation Center, NRCS, and USGS. This effort, involving a new website that will be called “Watermonitor.gov”, will combine water quantity information on streamflow, reservoir storage, ground-water storage, and snowpack storage, and will provide forecasts and links for further information. The USGS, through its Water Information Coordination Program (http://water.usgs.gov/wicp/aboutus.html), plays a strong coordinating role among federal and other government agencies involved in water information collection and dissemination. This role is supported by external advice from a Federal Advisory Committee Act group called the Advisory Committee on Water Information (ACWI), comprising representatives from Federal, state, local, and tribal governments, NGO’s, and the private sector. As noted above, EPA collects water-quality data from many different sources in its

STORET database, and EPA and USGS collaborate on Window to My Environment to provide a common portal to STORET and the USGS National Water Information System.

The U.S. Forest Service, which has a long history of programs to protect and manage water resources, has a Natural Resources Inventory System that has a significant component related to water (http://www.fs.fed.us/emc/nris/water/). This component focuses on data that describes aquatic habitats and stream morphology, watershed characteristics, water rights and uses, and aquatic organisms.

This system is heavily oriented toward geospatial information, including the National Hydrographic Dataset. The WATER Team has been chartered by the Natural Resources Information System directors to steward the WATER module - an ORACLE database and user toolset application with GIS connections. The WATER application is designed to implement corporate data standards and promote integrated management of aquatic resource information, including maps and related data about stream and lake systems plus water improvements and rights. This information can be analyzed and presented at multiple geographic scales, both within and across administrative and jurisdictional boundaries.

There is a significant effort underway in the academic community, in association with the National Science Foundation, to enhance collection and integration of hydrologic data. The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) seeks to advance hydrologic science in the 21st century through a broad based program of observations and research., CUAHSI (http://www.cuahsi.org) has evolved a science and implementation plan through a series of workshops, meetings, and other collaborative exercises. A primary purpose of CUAHSI is to help develop basic programs and infrastructure to support community research. The infrastructure elements include a system of hydrologic observatories, a hydrologic information system, a hydrologic measurement technology facility, and a hydrologic synthesis center.

The Sustainable Water Resources Roundtable (SWRRT) (http://water.usgs.gov/wicp/acwi/swrr/Rpt_Pubs/index.html) is a multi-agency organization aligned with other sustainable natural resources roundtables in an effort to define criteria and indicators that will enable us to monitor progress toward improving the sustainability of water resources. The SWRR criteria for sustainability of water resources, still a work in progress, are:

1. Ecological System.
   - Capacity to make water of appropriate quality & quantity available to support ecosystems
   - Integrity of ecosystems

2. Social System
   - Social well-being resulting from use of water resources
   - Social well-being resulting from use of water-related ecological resources

- Legal, institutional, community and technical capacities for management of water and related land resources for sustainability.

3. Economic System

- Capacity to make water of appropriate quality and quantity available for human uses
- Economic well-being resulting from use of water related land resources
- Economic well-being resulting from use of water- related ecological resources

The Heinz Center for Science, Economics, and the Environment released a comprehensive report entitled The State of the Nation's Ecosystems in 2002 (http://www.heinzctr.org/ecosystems/), with an update in 2003, and a follow-up report expected in 2007. Among the core national indicators are at least three related to water: water withdrawals, movement of nitrogen, and chemical contamination. The section on freshwater indicators (http://www.heinzctr.org/ecosystems/fr_water/indicators.shtml) lists 15 additional indicators specifically for the determination of the status of freshwater resources. These fall into categories of system dimensions, chemical and physical conditions, biological components, and human uses. According to the 2002 report, only 3 of the 15 indicators currently have "all necessary data available": streamflow, water withdrawals, and waterborne disease outbreaks. (Arguments could reasonably be made that the data for these three indicators is not totally sufficient.) Seven of the indicators have "partial data available", and the other five have "data not adequate for national reporting".

In December 2002, the White House Council on Environmental Quality (CEQ) launched a new effort to enhance coordination among federal agencies and to develop policy guidance on the future development of environmental and sustainable development indicators. The CEQ working group will:

- Develop agreement around a set of national-level environmental indicators that can be linked to regional and local conditions.
- Explore opportunities for collaboration among and between federal agencies, state, regional, and local agencies, nongovernmental organizations, and private-sector groups to improve the validity, reliability, consistency, and coverage of the data used for indicators.
- Consider how statistical reporting and data collection should be organized within the federal government, recognizing the data needs of agencies' programs and statutory authorities.

The goal of this effort is to have interlocking sets of environmental and human health indicators that can inform decisions at the local, state, regional, and national levels. Some of these indicators will relate to freshwater.

Crosswalk with Other Focus Areas

Some of the observables associated with water monitoring and protection may also covered under other IWGEO focus areas, and other chapters in section (4). This crosswalk is summarized in Table 1:

Observable	Disaster	Ocean	Climate	Ag/Land	Health	Ecosystem	Water
Precipitation			x	x			x
Snow			x	x			x
Precipitation quality					x	x	x
Streamflow	x	x	x			x	x
Surface water quality		x			x	x	x
Lake & reservoir storage	x		x	x		x	x
Evaporation & transpiration			x				x
Soil moisture			x	x			x
Ground water storage			x	x			x
Ground water quality					x	x	x
Drought	x	x	x	x	x	x	x
Water use				x		x	x
Drinking water					x		x
Land use			x	x		x	x
Impervious area			x	x			x
Wetlands				x		x	x
National Hydrography Dataset	x			x		x	x

Table 1: Related Societal Benefits

4. Major Gaps and Challenges

Many of the pieces for holistic monitoring of the nation's water resources are in place, but significant additional effort is needed to pull the programs together into a single coherent picture.

Table 2: Summary of Importance and Status of Water-Related Observables

Observable	Observed or Derived	Amenable to Remote Sensing?	Importance	Status	Gaps and Challenges
Precipitation	Observed	Yes	Important flux variable in the water cycle	Good national coverage with manual observing stations and radar networks	Need more real-time ground-based data for quantification. Preservation of long-term stations and their records. Need more stations on Tribal lands.
Snow	Observed: depth, cover Derived: water equivalent, melt rate	Yes	Important flux and storage variable; determines water supply for much of the West	Good national coverage from remote sensing and ground-based networks; some erosion of coverage of ground-based networks.	Maintain and expand coverage of SNOTEL stations. Expand coverage to the snowpack in the north central and northeastern states. Integrate *in situ* and remotely sensed data. Ground-truth snowmelt simulations.
Precipitation quality	Observed	No	Monitors acid rain and deposition of nitrate, sulfate, ammonia from airborne sources	Good national coverage through cooperative ground-based network; need to maintain coverage.	Maintain and expand network.
Streamflow	Observed: water level Derived: streamflow	Remote sensing may provide estimates for large ungaged rivers.	Important flux variable in the water cycle	Good national coverage through ground-based network; some erosion of coverage is occurring.	Currently the national network is funded 43% by state and local governments. Additional Federal funding is needed to maintain and expand the network. Research is needed on new non-contact and remotely sensed techniques for measuring streamflow.

Observable	**Observed or Derived**	**Amenable to Remote Sensing?**	**Importance**	**Status**	**Gaps and Challenges**
Surface water quality	Observed	Remote sensing can monitor plumes of sediment and algae.	Needed to understand watershed processes and guide anti-pollution efforts.	Many entities collect data; national networks are somewhat limited and could be better linked.	Enhance spatial, temporal, and parameter coverage. Develop new *in situ* and remote sensors for water quality. Integrate data from wide variety of sources. Improve data comparability.
Lake & reservoir storage	Observed: water level Derived: contents	Remote sensing can determine areal extent of water surface.	Important storage variable in the water cycle	Many reservoir operators collect the data; national coverage should be improved.	Integrate data from various sources.
Evaporation & transpiration	Derived	Can help with derived estimates.	Important flux variable in the water cycle.	National coverage could be improved.	Improve estimates. Improve spatial coverage of data to support estimates.
Soil moisture	Observed and derived	Can help with derived estimates.	Important storage variable in the water cycle.	National coverage could be improved.	Enhance spatial coverage of *in situ* network. Integrate remote and *in situ* data.
Ground water storage	Observed: water level Derived: storage	Can help with measuring subsidence caused by GW withdrawal; may estimate saturated thickness.	Important storage variable in the water cycle.	Some aquifers well monitored; most could use improvement.	Enhance spatial and temporal coverage of ground-water level monitoring.
Ground water quality	Observed	No	Needed to understand aquifer processes and guide anti-pollution efforts.	Some national coverage but most efforts are local and not well linked.	Enhance spatial, temporal, and parameter coverage. Integrate data from various sources.

Observable	**Observed or Derived**	**Amenable to Remote Sensing?**	**Importance**	**Status**	**Gaps and Challenges**
Drought	Derived	Yes	Needed to guide water-supply decisions and conservation efforts.	Good collaborations exist that integrate available data; some improvements possible.	Need research on better combinations of indicator parameters. Better coverage of some indicator parameters. Better integration of data from various sources. Need funding for NIDIS.
Water use	Observed and derived	Can monitor extent of irrigated farmland.	Important flux variable in the water cycle.	Good coverage for some categories; estimates in others, better temporal reporting needed, better monitoring of consumptive use needed.	More precise estimates of certain uses, e.g., irrigation. Need better temporal resolution and better monitoring of consumptive uses.
Drinking water	Observed and derived	No	Needed for linking water and human health.	Good locational data available (not publicly), some good national datasets on compliance and contaminants.	Better spatial, temporal, and parameter coverage. Better integration of data from various sources.
Land use	Observed and derived	Yes	Needed to understand and predict the links between land use and water.	Good national coverages available; need to be linked to watersheds.	Provide land-use/land-cover data specific to a given watershed. Need better understanding of links between land use and water quality and quantity.
Impervious area	Derived	Yes	Determines whether water infiltrates or runs off.	Could be derived from remote sensing; not currently available nationwide.	Derive better and more up-to-date estimates of impervious area for a given watershed.
Wetlands	Observed	Yes	Describes important ecosystem for hydrology and water quality.	Good national coverage.	Maintain and enhance coverage.
National Hydrography Dataset	Derived (not actually an observable; more like a partnership or a tool)	Yes	Provides common spatial representation of all surface water data; could serve as the basis for an integrated system.	Good national coverage; needs some improvements.	Complete national coverage at the 1:24,000 scale. Take care of edge-matching issues. Associate stream reaches with other water-related data.

5. Future Earth Observation Systems that May Fill Gaps

For some observables, such as lake and reservoir quality, transpiration, ground-water storage, ground-water quality, ground-water recharge and discharge, and water use, improved data collection efforts are needed. For example, in monitoring water use, we do a fairly poor job of accounting for consumptive water use. We should account for all the water that falls as precipitation, evaporates, percolates to ground water, or runs off into the stream network, and then follow that water through the natural hydrologic cycle, as well as track all the human modifications to the natural cycle. We should be able to answer "how much?" and "where?" for all these processes. We currently don't have a very complete or integrated accounting for human water withdrawals and consumptive use, and what we have is not collected on a frequent time scale. Much of this information is collected by irrigation companies and farmers, but there is little effort to collect and assemble the data.

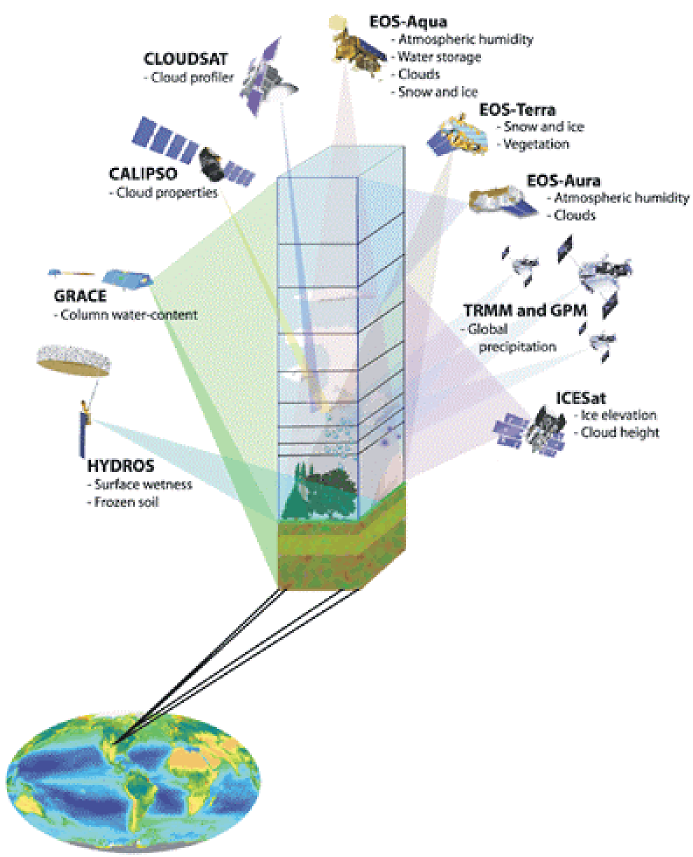
For other observables, such as streamflow, stream water quality, and snowpack depth and water equivalent, good monitoring programs are in place but efforts are needed to prevent the loss of monitoring stations and enhance geographic coverage. Coverage of all the water-related observables in Indian Country should be enhanced.

Extension of monitoring efforts to relevant worldwide monitoring is needed to provide the global context in which the nation's resources fit. International water data are important not just to those in foreign countries, but also to many in this country. For example, American farmers are keenly interested in weather and water conditions in similar farming areas in other parts of the world. Much of the international water data collection effort is being coordinated under the Global Energy and Water Cycle Experiment (GEWEX). This is a program initiated by the World Climate Research Programme (WCRP) to observe, understand and model the hydrological cycle and energy fluxes in the atmosphere, at land surface and in the upper oceans. GEWEX is an integrated program of research, observations, and science activities ultimately leading to the prediction of global and regional climate change. The International GEWEX Project Office (IGPO) is the focal point for the planning and implementation of all GEWEX Projects and activities.

GEWEX is conducted as part of the Integrated Global Observing Strategy (http://www.igospartners.org/). The Integrated Global Observing Strategy (IGOS) seeks to provide a comprehensive framework to harmonize the common interests of the major space-based and *in situ* systems for global observation of the Earth. It is being developed as an over-arching strategy for conducting observations relating to climate and atmosphere, oceans and coasts, the land surface and the Earth's interior. IGOS strives to build upon the strategies of existing international global observing programs, and upon current achievements. It seeks to improve observing capacity and deliver observations in a cost-effective and timely fashion. Additional efforts will be directed to those areas where satisfactory international arrangements and structures do not currently exist. IGOS is a strategic planning process, involving a number of partners, that links research, long-term monitoring and operational programs, as well as data producers and users, in a structure that helps determine observation gaps and identify the resources to fill observation needs. One part of the IGOS program, the Integrated Global Water Cycle

Observations (IGWCO) theme, is needed to provide monitoring data and contribute to improved predictions for variables such as precipitation, soil moisture and runoff over many times scales and spatial scales from local to global. IGWCO is also needed to address several critical science questions regarding the role of the water and energy cycle in maintaining the stability of the Earth's climate system, feedback processes involving clouds and land surfaces that influence regional and global climate change, and the availability of fresh water resources.

The observations required to advance our understanding and modeling of these and other science questions cannot be adequately addressed through continued reliance on *ad hoc* observing systems. In August 2002, the World Summit for Sustainable Development (WSSD) in Johannesburg recognized the paramount importance of water issues and encouraged supporting global observations for improved understanding of the global water cycle. The Water Cycle Theme will be built on the experience of projects, such as the WCRP's Global Energy and Water Cycle Experiment (GEWEX), that deal with the development of global data sets for clouds, precipitation and other important water-cycle variables such as soil moisture, evaporation/evapotranspiration, energy and radiation budget parameters, among others.



As has been shown in some of the above sections, remote sensing can be an effective observational tool for many types of hydrologic measurements. Continuing research and ground-truth is needed to develop and refine remote-sensing tools for use in hydrologic observations. For example, the National Aeronautics and Space Administration (NASA) has an Earth Science

Enterprise program on Water and Energy Cycles (http://watercycle.gsfc.nasa.gov) that seeks to use advanced remote sensing to support improved hydrologic predictions. The aim is to improve/nurture the following global measurements: precipitation (P), evaporation (E), P-E and the land hydrologic state, such as soil-water, freeze/thaw and snow. NASA is exploring an integrating water-cycle mission which would observe water molecules through the atmosphere and land surface using an active/passing hyperspectral microwave instrument. There is a need to develop a greater understanding of the capacity of remote sensing to contribute to the observational database for water, and to prioritize the various satellites and sensors under consideration for development.

NASA's Earth Observing System (EOS) Science Plan (http://eos.nasa.gov) contains major sections on observing and modeling hydrologic processes using remote sensing.

Input - Output = Storage Change

Transport + Evaporation - Precipitation - Runoff – P
=
D**Land Storage+** D**Water Vapor**

As with all the Earth-observing systems, there is a need to integrate data pertaining strictly to water with data pertaining to the interactions of humans with water and with their natural environment. Some of these data are best collected by social and economic scientists, but they must be integrated with the data discussed in this subchapter to provide a broad understanding of the issues surrounding water and its uses.

The 1995 Final Report of the Intergovernmental Task Force of Monitoring Water Quality (the forerunner to the current National Water Quality Monitoring Council under the Advisory Committee on Water Information) lists several suggestions for improving and integrating water quality monitoring data in its Major Conclusions and Recommendations (http://water.usgs.gov/wicp/itfm.html). Among the conclusions:

- Tens of thousands of public and private organizations monitor water quality for a wide variety of objectives.
- Total annual expenditures in the public and private sectors to control water pollution are tens of billions of dollars and climbing. Monitoring is necessary to judge the effectiveness of these investments.
- In the last decade, it has become clear that monitoring activities need to be improved and integrated better to meet the full range of needs more effectively and economically.

- A new monitoring approach is required to target water-pollution-control resources to priority concerns and to evaluate the effectiveness of actions taken to prevent or remediate problems. A better balance of ambient and compliance monitoring is needed.

A 2002 Report to Congress, "Concepts for National Assessment of Water Availability and Use" (USGS Circular 1223) (http://water.usgs.gov/pubs/circ/circ1223/) also contains some useful conclusions and recommendations pertaining to water monitoring:

"The assessment would develop and report on indicators of the status and trends in storage volumes, flow rates, and uses of water nationwide. Currently, this information is not available in an up-to-date, nationally comprehensive and integrated form. The development and reporting of national indicators of water availability and use would be analogous to the task of other Federal statistical programs that produce and regularly update indicator variables that describe economic, demographic, and health conditions of the Nation. The effort to develop indicators should comply with the Office of Management and Budget Information Quality Guidelines. The assessment also would provide regional information on recharge, evapotranspiration, interbasin transfers, and other components of the water cycle across the country. This regional information would support analyses of water availability that are undertaken by many agencies nationwide and would benefit research quantifying variability and changes in the national and global water cycle…"

"The assessment should be highly collaborative, involving many Federal and State agencies, universities, and non-governmental interests…To maximize the utility of the information, the design and development of the assessment should be coordinated through the Federal Advisory Committee on Water Information."

6. Interagency and International Partnerships

Federal Interagency:

- Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality
- Interagency Working Group on Earth Observations
- Advisory Committee on Water Information
- National Water Quality Monitoring Council
- Water Information Sharing and Analysis Center (Water ISAC)
- Window to My Environment (EPA and USGS)
- Many bi-lateral and multi-lateral interagency collaborations

Federal-State-Tribal-Local:

- Cooperative programs with Federal agencies

- Interstate Council on Water Policy
- Regional water councils
- River basin commissions
- Conservation Districts

Government/NGO/Academia/Private sector:

- National Drought Mitigation Center
- Stakeholder and advisory groups
- Watershed organizations

7. U.S. Capacity Building Needs

The gaps and challenges identified above could be addressed by development of consistent, nationwide databases for hydrologic data. This data would form the basis for reliable assessments and predictions of current and future conditions under various scenarios, as well as enhance our understanding of fundamental hydrologic processes. On a global scale, these needs are especially pronounced in the developing world.

8. Conclusions

The gaps and challenges identified in Table 2 and the text above indicate much work to be done in this area. These efforts could be coordinated through the CENR Subcommittee on Water Availability and Quality. There are promising indications that some hydrologic parameters such as soil moisture, transpiration, sediment flux, and some others may be monitored from space using satellites. There is also increasing use of interferometric synthetic aperture radar remote sensing to monitor changes in the ground surface due to changes in ground-water storage in underlying aquifers. Future enhancements of remote-sensing platforms may identify other hydrologic parameters that can be adequately monitored from space, especially where ground-based monitoring systems are lacking. Monitoring systems based on remote sensing will require adequate ground-truth data collected by *in situ* methods. Monitoring systems based on *in situ* methods should be maintained and expanded, and should be developed for parameters with currently inadequate coverage.

As mentioned above, the National Hydrography Dataset (NHD) serves as an integrating commonality for all data related to the surface-water flow system. It could be central to designing a water-data integration and retrieval system that could track water as it moves throughout the natural and human water cycle, including ground water. Additional work needs to be done on the NHD, such as completion of high-resolution hydrographic mapping on a nationwide basis, verification of flow relationships, and ensuring that point data are associated with individual stream reaches. Beyond the reach network itself, there must be strong connections with watershed boundary datasets. A project is underway to derive crude watershed boundaries from NHD using Thiessen polygons, but a more accurate approach would involve linking NHD with digital elevation models (DEM's) and using a process such as "burning and ridging" to define topographically accurate watershed boundaries. With these linked geospatial systems in place, and the appropriate connections with other data described above, we could design a data integration and retrieval system that would let the user point to a location on a stream, automatically derive a watershed boundary for that point, and then retrieve integrated point and area hydrologic data, from both ground-based and remote-sensing systems, sufficient to describe the hydrologic characteristics of that watershed and follow the flow of water through it.

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APPENDIX 1
Sidebars on Uses of Hydrological Data

GEWEX Americas Prediction Project

The GAPP program (GEWEX [Global Energy and Water Cycle Experiment] America Prediction Project) objectives are to make monthly to seasonal predictions of the hydrological cycle and to use these improved predictions for better water resources management.

The first objective largely involves improving the land surface, hydrology, and boundary layer representations of models used for climate prediction through improved understanding of the hydrological processes, feedbacks between the land and atmosphere, model transferability, and development of a comprehensive modeling system.

The second objective involves scaling the climate model output to make it useful for water resource managers, improved understanding of the links between hydrologic predictions and water resources management, including the use of demonstration projects, and better understanding of the effects of land surface changes on the regional hydrology. Two major new initiatives will be the effect of orography on the hydrological cycle of the Western Cordillera and the predictability of the North American Monsoon (NAMS) and its effects on summer precipitation over the USA.

The other components all relate to improving the predictability of the hydrological cycle with special regards to the land surface and the role of predictions for water resources management.

Uses of Streamflow Data

Information on the flow of rivers is a vital national asset that safeguards lives and property and ensures adequate water resources for a healthy economy. The U.S. Geological Survey (USGS) operates about 7,000 streamflow-gaging stations that keep watch on the Nation's rivers. The vast majority of these stations are jointly funded in partnerships with more than 800 State, local, tribal, and other Federal agencies. The USGS network provides real-time and long-term historical streamflow information that is accurate and unbiased, and that meets the needs of many users. For example, streamflow information is needed for:

- Flood forecasting and flood-prone area mapping,
- Planning and managing water supplies and upholding interstate compacts,
- Developing water-quality standards and monitoring changes in flow,
- Designing structures such as dams, levees, bridges, and highways.
- Avoiding unsafe or unpleasant river conditions when recreational water users plan their trips for fishing, canoeing, kayaking, or rafting.
- Monitoring long-term changes in the climate.

"Streamflow data…form the cornerstone for national, regional, and local efforts…by providing continued, up-to-date information about water conditions and understanding of hydrologic phenomena." –National Research Council.

"The information your web page provides was very useful to our Emergency Preparedness team." --Steve Durst, Sumner County Emergency Preparedness, Welling, Kansas.

"The federal cost of basic water data collection and analysis pales when compared to the cost of facilities which will be based on inadequate data, as well as to the potential loss of life and property that can occur if errors in design result from use of a faulty data base." –American Society of Civil Engineers.

Water 2025

Water 2025 (http://www.doi.gov/water2025/) is a new problem-solving initiative by the U.S. Department of the Interior that will help manage scarce water resources in the western U.S., and develop partnerships to nourish a healthy environment and sustain a vibrant economy. In some areas of the West, existing water supplies are, or will be, inadequate to meet the demands for water for people, cities, farms, and the environment even under normal water supply conditions. For Fiscal Year 2025, 19 projects have been identified in 10 western states to enhance understanding and management of scarce water resources so that conflicts will be avoided or minimized. Projects will focus on water marketing, conservation, augmentation, and management. Underlying these projects will be a continuing need for reliable, impartial data about the water resources subject to conflict.